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No. 550

COMBATING AIRPLANE FIRES

By Henri Brunat

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P R E F A C E

At the request of the Technical Commission of the French Committee for Aeronautical Propaganda, Mr. Henri Brunat, Chief of the Central Safety Service in the Air Ministry has given, for the benefit of pilots and mechanics, a summary of the important steps to be taken in combating airplane fires. I feel it a pleasant duty to introduce this work. Here, as in many other cases dealing with safety, the technical elements of the problem are the basis of the work. It is less a question of inventing new devices than of bringing the necessary safety routine into the everyday life of aviation. The simple principles which prevent fire and its consequences should be considered in the choice of materials. All the rules, which are now strictly defined, should be applied to the details of construction, such as the layout of the pipes, their attachments and connections.

Of course, every possibility is open to further technical progress in the field of new fuels and engines. Yet, to neglect the present resources in favor of a hypothetical future would mean to accept useless sacrifices which aviation should no longer allow and to show lack of sound judgment and character. To serve the cause of safety means, at the same time, to serve that of aviation. It is not merely a duty of humanity but the necessary condition of its development.

In devoting a new study, after so many others, to a vital question for aviation, the French Committee for Aeronautical Propaganda has adopted the surest and most fruitful solution, that of instruction and information, without which no permanent improvement can be effected. The Committee has secured the assistance of Mr. Brunat, who has had a long experience in air navigation services. He has succeeded in keeping above his daily task, correlates his scattered observations and is concise while being thorough. I congratulate him most cordially.

Laurent Eynac.

F O R E W O R D

"To all those interested in increasing the safety of flight."

During a recent meeting of the Technical Commission of the French Committee for Aeronautical Propaganda, whose object is to increase the safety of flight, the president of the commission asked me to make a report on the conditions under which airplane fires had hitherto occurred in flight and on the ground.

On hearing this report, the commission was greatly impressed by the number of serious accidents which might have been avoided by a few simple precautions. It was also struck by the fact that no such precautions had been taken by those in charge of the material nor by the pilots, some of whom lost their lives by an unsuitable maneuver or by a small defect which could easily have been remedied.

The discussion, which took place between manufacturers, engineers and pilots, showed that these precautions had been neglected merely because they were insufficiently known, whence the necessity of filling this gap. The present report is intended to do this. The wording is as simple as possible so as to be readily understood by the designer as well as by the mechanic, since they must both contribute toward increasing the safety of flight.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 550.

COMBATING AIRPLANE FIRES.*

By Henri Brunat.

A i r p l a n e F i r e s
General Considerations

The origin of a fire can always be traced back to two initial causes: the collecting of fuel or oil at some point in the airplane (usually inside the engine cowling) and the flashing of a spark or flame which sets fire to the inflammable matter or to the vapor-laden air. The presence of fuel or oil in the engine cowling is due, in most cases, to a partial break in a pipe, to the loosening of a joint by the vibrations, to an imperfectly closing carburetor float chamber which lets some of the fuel escape during stunt flying, or else to the breaking open of the float chamber. It sometimes happens that insufficiently cooled oil becomes too thin and leaks through the engine joints. A faulty connection of the ignition circuit or a badly protected magneto may let a spark flash and start a fire. The principal cause, however, of the ignition of the fuel, oil, or carbureted air, which has collected inside the cowling, is chiefly back-firing to the carburetor (Fig. 1).

*"La Lutte contre l'Incendie à Bord des Avions." Booklet published by the Comité Français de Propagande Aéronautique, Paris.

All internal combustion engines working on the carburetor principle are subject to back-firing, whatever fuel is used. In fact, back-firing takes place inevitably when the gaseous mixture burning in the cylinder comes in contact with the intake pipe. This may be due to badly timed or poorly closing valves or to the fact that the mixture, being insufficiently homogeneous, too poor or too rich in fuel, or poorly ignited, continues to burn after the intake valve opens. The violence of back fires is a function of the volume of each cylinder and of the volume of the gaseous mixture which explodes in the intake pipe. Hence the danger of fire due to back-firing increases with the engine power.

In addition to these general causes, which are at the origin of most fires following the starting of engines, in flight, and of certain fires on the ground subsequent to crashes, accidents are often caused by the ignition, after atomization, of fuel projected by the impact into or against the exhaust pipes or manifolds.

We shall now consider how fire breaks out and spreads in each particular case, since the conditions under which it can develop change considerably according to whether it takes place after the starting of the engine, in flight, or after a crash.

A Few Examples of Airplane Fires

At the start.— In order to facilitate the starting of the engine, the mechanic injects fuel into the cylinders and floods the carburetors. The gaseous mixture, which fills the cylinders after swinging the propeller, is rich in fuel but, the air being cold, the fuel is not completely atomized and remains partly in the form of small drops.

When the engine is started, the combustion spreads too slowly through the insufficiently carbureted mixture and the intake valve opens before the combustion of the gas is completed. The gases in the intake pipe then ignite and explode, constituting what is known as back-firing to the carburetor. The flames break through the air intakes in spite of the protective metal grids with which they may be provided and come into contact with the fuel flowing through these pipes, or with the carbureted air in the neighborhood. Fire is started and spreads, if it finds fuel. Small fuel or oil leaks and oil residues, adhering to the insufficiently cleaned engine or to the airplane in close proximity to the engine, are the most frequent causes of fire propagation.

In flight.— First, the vibrations cause the partial rupture of a pipe or the loosening of a joint. A certain amount of fuel intended for the carburetor flows into the cowling. The underfed carburetor supplies the engine with too lean a mixture,

whence there results, for the reasons outlined above, a succession of back fires. The flames blown back into the intake pipe come into contact with the fuel flowing from the engine cowlings and fire breaks out. It feeds on the fuel from the leaky pipes and sometimes on the oil escaping through the engine joints. If the fire is not at once effectively combated, it develops and spreads rapidly to the fuselage as soon as the fuel and oil flow freely into the cowlings after the burning of the rubber connections. (Fig. 2). It spreads still more rapidly, if the flames reach the walls of the fuel or oil tanks, which give way under the increased internal pressure and spill their contents. In this case the whole airplane takes fire. The premature dislocation of the tanks is sometimes caused by the explosion of fuel vapors collected near by.*

Second, the cover of the float chamber may lack the proper degree of tightness and allow the fuel to leak into the cowlings, either during stunt flying or for some accidental cause such as a burst float chamber or jammed needle valve. The slow combustion of too rich a mixture causes back fires to the carburetor which start a fire when they come in contact with the fuel flowing from the cowlings or with the carbureted air produced by its vaporization.

Fires, however, following fuel leakages from the float cham-

*In the following paragraphs the description of the successive phases of a fire will not be repeated, since they are nearly the same in all cases.

ber, are due in most cases to an inopportune maneuver of the pilot, who opens the gas throttle too suddenly after an acrobatic maneuver, or after a descent during which the engine has cooled off. Back-firing then takes place for the same reasons as at the starting of the engine.

Third, the breaking of a connecting rod sometimes causes fire. This may occur in three different ways:

- a) The breaking of a connecting rod entails a sudden reduction in the engine speed before the latter is completely stopped and causes back-firing which coincides with the severing of the carburetor or fuel pipes by a connecting rod staving in the crank case. Fuel flows freely at the point swept by the back fires and the conflagration breaks out (Fig. 3).
- b) The carburetor and fuel pipes are not torn off but back fires come into contact with the oil vapors escaping from the crank case. The oil in the cowling then catches fire.
- c) The engine stops suddenly. The explosion crushes the piston end, passing through the broken crank case, sets fire to the oil vapors which escape into the open air. The oil then catches fire.

Fourth, a break of the propeller or of the cam shaft causes, at the same time, but for different reasons, vibrations and back-firing into the carburetor. Fire breaks out if the vibrations cause a fuel leak in the neighborhood of the air intakes. Back fires may be caused by a foreign body in the fuel piping, by the ill-timed admission of air, by a badly closing inlet valve, and sometimes even by the failure of one of the two ignition circuits. Fire breaks out if, at the same moment, there is fuel, oil or carbureted air in the neighborhood of the air intakes.

Fifth, the loose end of a spark-plug wire, in the neighborhood of the metal ground connected with the engine, may produce sparks which cause fire when they come in contact with inflammable substances or carbureted air (Fig. 4). Fire also breaks out when a spark flashes from the electric circuit or any of its accessories, at a point where fuel or oil vapors have accidentally accumulated.

On landing after breaking of the propeller.-- During a bad landing, with engine running, the propeller breaks on striking the ground. The result is a sudden change in the engine speed accompanied by back fires. Fire breaks out if the flames, which break forth from the intake pipes, encounter fuel flowing from the pipes broken by the impact.

After a crash caused by striking the ground or an obstacle.--

Two main causes enable the fire to break out:

- a) The ignition of the fuel or oil, flowing from broken pipes, by back fires due to sudden changes in the engine speed subsequent to the breaking of the propeller on striking the ground, a cause already mentioned.
- b) The ignition of the fuel, oil, or their vapors on coming in contact with very hot portions of the pipes or exhaust manifolds, following the crushing of the tanks against the engine. The rapidity with which fire spreads on the ground depends on the proximity of the fuel and oil to the engine (Fig. 5).

Means Suggested to Reduce the Danger of Fire

The preceding study of the most frequent conditions under which fire breaks out leads to the conclusion that such accidents can be easily avoided, provided the aircraft are built and kept in such a condition that fuel, oil, or carbureted air cannot accidentally come in contact with a spark, flame, or very hot portion of the engine.

The measures to be taken to reduce the danger of fire should therefore tend toward:

First, preventing fire from breaking out, by avoiding all fuel and oil leaks, the flashing of sparks and flames and insur-

ing a sufficient cooling of the portions of the engine capable of reaching very high temperatures, so as to prevent them from igniting the carbureted air with which they may come into contact after a crash.

Second, preventing fire from starting and combating it when the measures taken to prevent its inception prove insufficient owing to some mechanical defect or to lack of care. This result can be attained by the measures considered below.

No main or gravity fuel tank or oil tank or even fuel pump should be placed inside the engine cowlings, so as to avoid incendiary relays near places where fire may break out. Whenever possible to locate them elsewhere, the tanks should not be placed directly behind the engines, so as to avoid the splashing of fuel and oil on the exhaust manifold and carburetors, in case the airplane should crash against the ground or an obstacle.

Tanks should be provided with quick-emptying devices designed to release the fuel far enough aft to prevent its coming in contact with any portion of the airplane and being set on fire at the moment of emptying (Fig. 6). If an airplane cannot be equipped with quick-emptying tanks, as specified above, it should be provided with dumpable tanks.

Each pipe should be provided with a quick-closing emergency cock, close to the tank, in order to enable the pilot to stop the fuel or oil delivery, if a pipe should break or a joint loosen. When fuel is not supplied to the engine by gravity,

there should be adopted a system of pipes entering the top of the tank, so the fuel cannot flow outside due to a leak in the pipe (Fig. 7).

The design and construction of tanks, their bearing points and attachment fittings should receive particular care, in order to insure absolute tightness in spite of the stresses exerted on the tanks by accelerations in flight, by the surging action of the liquid and by vibrations.

Fuel and oil pipes should be run in such a manner as to allow for expansion and contraction without subjecting the joints to stresses that might cause leaks. Pipes of annealed copper are better than any other kind because they are less breakable. The pipes should be secured to fixed portions of the airplane, such as the engine block and fuselage, in order to reduce the magnitude of the vibrations. Sliding attachments should be provided near hot spots so as to allow for expansion.

Strong rigid metal joints should be used in preference to flexible joints for inert portions of the piping. Flexible joints should be used for connections between the pipes of the engine and fuselage. Use fireproof joints or joints provided with fireproof covering, in order to prevent their destruction by incipient fire and the flow of fuel and oil toward the fire.

Use flexible joints that are not affected by the fuel, or else use an internal protective coating. Particles of the joint in the pipe cause under-feeding of the carburetor and back fires.

Other qualities being equal, preference should be given the lightest flexible joints because the vibrations will be less pronounced. Reduce the number of joints as much as possible, even if this should increase the difficulty of removing the pipes. The more we reduce the number of joints, the smaller will be the danger of leakage.

At an easily accessible point of the pipe outside the engine cowl, install a receptacle of sufficient capacity to retain the dirt and water which may accumulate in the fuel during flight. The use of such a receptacle will prevent back fires.

Flexible pipes are not affected by vibrations and may be very useful, if they are incombustible and are not affected by the fuel. The latter condition is the least important, since frequent inspection permits replacing the pipes in time.

In order to avoid the production of dangerous sparks:

Use ignition-wire covers near the spark plugs, so as to prevent loose wires from coming in contact with the crank case and engine cowl, where fuel and oil residues may have collected. Adequately insulate and protect the ignition circuit, the electric wires and their accessories (Fig. 8). Locate the electric system where accidental fuel or oil leaks or fuel vapors accumulating at some point of the airplane cannot come in contact with it. Do not put storage batteries where fuel vapors or explosive gases may collect while the batteries are being charged. Place the magnetos as far from the carburetors as possible and

protect them from fuel and oil splashes. Use special vibration-proof connections. Leave sufficient space between binding posts to reduce the danger of short circuits. Shield electric accessories capable of producing sparks.

The degree of reliability of operation being equal, preference should be given engines of the dry-sump type. The danger of fire due to the breaking of a connecting rod will thus be reduced. For the same reason, do not locate the pipes and the carburetor where they might be torn off by the breaking of a connecting rod.

Equip the engine with an oil radiator and, if necessary, increase the delivery and the speed of circulation of the lubricant, in order to maintain its viscosity at the proper degree to prevent its leaking through the engine joints.

The breathers should be run to the outside, in order to prevent oil vapors from remaining in the engine cowl.

Secure the air intakes firmly to prevent their being broken by violent back fires. Make sure of their perfect tightness, so that the flames blown back into the pipe cannot pass into the cowl. They should be located outside of the cowl (Fig. 2) but not under it, in order to avoid the danger of fuel and oil, accidentally dripping on them, being ignited by back fires. Besides, by placing the air intakes high enough on the side or on top and forward of the cowl, their breaking, after accidents to the landing gear, will often be avoided. This will also re-

duce to a certain degree the danger of fire on the ground due to back-firing. Fit narrow-meshed metal grids in the openings of the air intakes. They may prevent the passage of back fires if the latter are not too violent.

Encourage the fitting of engines with special carburetors working on the fractional carburetion principle (Fig. 10). Their use should enable the complete elimination of fuel from the engine cowlings and thus remove one cause of fire.

Use anti-backfire devices. Certain types which consist of metal surfaces inserted in the suitably widened inlet pipe parallel to the gas flow are very effective in cooling and stopping the flames (Fig. 11). The loss of power which they cause is negligible. The general use of anti-backfire devices should permit of greatly reducing the danger of fire when starting the engine, both in flight and on the ground.

Use spark plugs that do not cause auto-ignition, even when the engine is very hot. In most cases an airplane on crashing to the ground, catches fire because the engine continues to run either because the pilot failed to switch off the ignition or by auto-ignition.

Do not bore holes in the exhaust pipes in order to facilitate fuel injection into the cylinders. The flames or red-hot residue which come out of these holes may set fire to the fuel vapors accidentally escaping from the cowlings. Lack of tightness of the exhaust pipes also presents a danger after an accident which causes the crashing of the airplane. The fuel spilled on

the ground fills the air with vapors which may catch fire on coming in contact with the internal hot spots of these pipes. Use pipes and exhaust manifolds designed and arranged to be kept at a sufficiently low temperature, even inside the cowl, so that fuel vapors coming in contact with them will not take fire on the ground.* Manifolds should be provided with effectual devices for preventing the flames from bursting forth under normal conditions and during sudden variations of engine speed. If exhaust pipes are provided, they should be mounted so as to reduce as much as possible the danger of dislocation in case of an accident. These pipes should, if necessary, terminate far enough from the fuel/^{drain} to prevent the released fuel or its vapors from being ignited by the exhaust gases. Use a heating device for the carburetors and inlet pipes which assures the necessary degree of homogeneity of the gaseous mixture to prevent its causing back fires owing to its too slow combustion. No device should be used that might allow hot exhaust gases to penetrate accidentally into the carburetor or the intake pipe. If the heating is done with hot air, the installation of the air intakes should exclude the possibility of low points where fuel might accumulate.

Use incombustible materials for the construction of the engine bed and design it with the minimum of reentrant angles, in order to reduce the danger of accumulation of inflammable residues.

*The power absorbed by the manifolds in flight can be reduced to zero, if their outlets are designed to produce great negative pressures accelerating the exit of the gas. This means should also enable the reduction of the temperature of the valves.

Isolate the engine from the rest of the airplane by a perfectly tight fireproof bulkhead (Fig. 12). Its edges should be carried back along the walls of the fuselage, so as to prevent flames in the engine cowlings from easily getting behind it. This bulkhead should also be designed to protect the pilot from the poisonous carbon tetrachloride vapors emitted by the extinguishing liquid.

Wooden portions of the airplane, located immediately behind the engine, such as wing struts, spars, etc., should be protected by impervious fireproof sheaths, if their destruction by fire is liable to cause the wings to break off.

Drain holes should be provided at all low points of the airplane where fuel or oil might accumulate accidentally. Their location should enable them to fulfill their purpose both in flight and on the ground and to prevent the evacuated inflammable liquid from coming in contact with the exhaust gases.

Adequate and suitably arranged openings should be provided to enable, in flight, a thorough ventilation of the engine cowlings and of the airplane compartments where fuel vapors might collect, if a tank or pipe should spring a leak (Fig. 13). Air scoops should be provided on seaplanes, in order to insure a good ventilation of the tank compartments. In order to increase the efficacy of the fire extinguishers, means should be provided for the crew to take immediate action, if fire should break out. Every engine which cannot be seen should be provided with a

fire alarm. Simplify as much as possible the operation of the extinguisher. Every second lost allows the fire to spread.

On multi-engine airplanes use a "fire-prevention" control which, in a very short time, cuts the ignition of each individual engine, stops the fuel and oil supply, closes the radiator shutters (if the airplane is equipped with a frontal radiator) and operates the fire extinguisher.

Increase the number of nozzles, if necessary, and arrange them so as to cause the extinguishing liquid to be projected simultaneously on the carburetors, the fuel and oil pipes, the walls of the crank case, and the portions of the cowl located directly under them. Taking into consideration the air currents which form in the cowl, direct the jets so that the extinguishing liquid will reach the right points in flight.

Use extinguishers designed to be operated three or four times in succession, in order to facilitate the intervention of the pilot as many times as necessary, in case the fire should not be completely extinguished or another should break out. If the extinguisher works with the aid of cylinders of compressed air or gas, see that the cylinders are well charged before each flight. Make sure, by frequent inspections, that the extinguisher pipes are in good condition. A hand-operated extinguisher, producing no poisonous gases, should be placed in each occupied compartment (pilot's cockpit, cabin, etc.).

Suggestions to Mechanics

Do not leave unsupported fuel pipes in the inert portions of the airplane (power plant and fuselage). This may result in vibrations causing dangerous leaks. Keep the fuel and oil systems (tanks, cocks, pipes, joints, carburetors) in excellent condition. Do not hesitate to replace a joint, if it looks doubtful.

Inspect the whole electric circuit often and make sure that it is clean, well insulated and protected, and that all the connections are properly tightened.

Never leave even the smallest particle of fuel or oil on any part of the engine or airplane. Do not forget to clean the tank compartments and the portions of the airplane located between the floor and the bottom of the fuselage, although these points are not always readily accessible.

If you inject fuel, in order to facilitate the starting of the engine, do not inject too much. Keep in mind that a thimbleful is quite sufficient to start even a powerful engine. Before starting the engine, wipe off the fuel that may have gotten into the cowlings or on the air intakes, until these portions of the airplane are perfectly dry.

Do not start the propeller by hand. A good starter will do this work better. The engine, started at greater speed by this device, will work more easily and with less danger of back-firing.

Suggestions to Pilots

Do not allow your engine to cool too much during a descent or in stunt flying. It may cause back fires in picking up. In order to pick up, open the gas throttle very gradually (Fig. 14). Otherwise you run the risk of causing back fires and setting the airplane on fire, if sufficient fuel or oil has collected in the vicinity of the air intakes.

When you are maneuvering to land on unsuitable ground, cut the ignition and shut off the fuel supply about 60 feet above the ground. You will thus reduce the danger of fire in case your airplane should crash in landing. Cut the ignition if you stall near the ground. You have thus a chance of avoiding fire on the ground.

If fire breaks out in the engine cowlings, cut the ignition and thus prevent back fires that may revive or start the fire anew. Shut off the fuel and oil supply. If necessary, close the radiator shutters, in order to prevent the tetrachloride vapors from being immediately expelled from the cowlings, and start the extinguisher. If these suggestions are followed, the chances of extinguishing the fire will be increased.

C o n c l u s i o n s

At first sight, the measures and precautions recommended for reducing the danger of fire may seem many and complex. As a matter of fact, they are very few and simple and will natural-

ly come into one's mind, provided the causes of accidents are clearly understood.

The use of safety devices, now fully developed and prescribed by the Air Minister, the work of the engineer in designing and building the airplane, that of the mechanic in choosing the material and even the action of the pilot in flight will greatly reduce the danger of fire.

The application of the above methods involves no new technical problem and can therefore be accomplished in a very short time. It is merely a question of will on the part of those in charge of designing, building, and using airplanes.

Translation by
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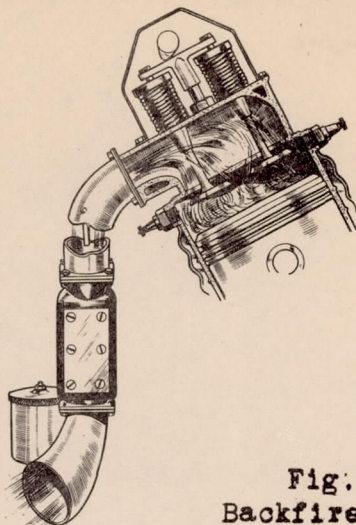


Fig.1
Backfire.

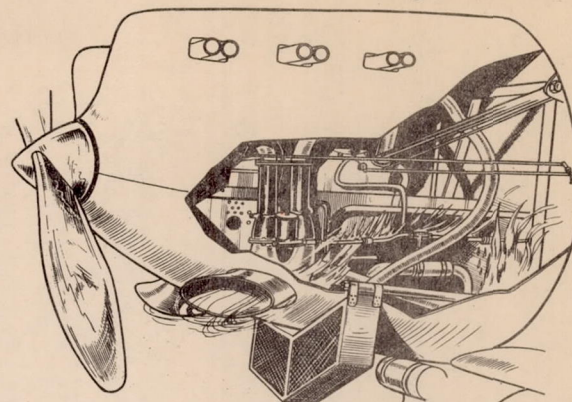


Fig.2 Fire following a fuel leak
in the cowling.

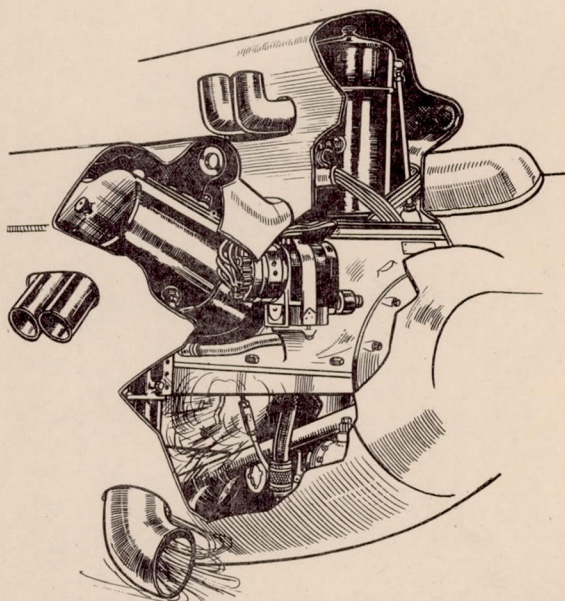


Fig.3 Fire caused by the
breaking of a
connecting rod.

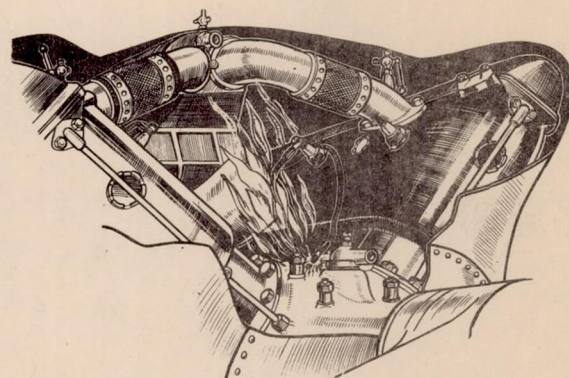


Fig.4 Fire caused by a detached
spark - plug wire.



Fig.5 Fire on the ground
after a crash.

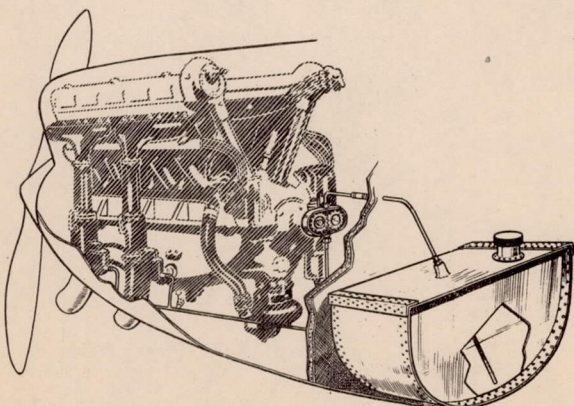


Fig.7 Pumping fuel through
tube entering top of
tank.

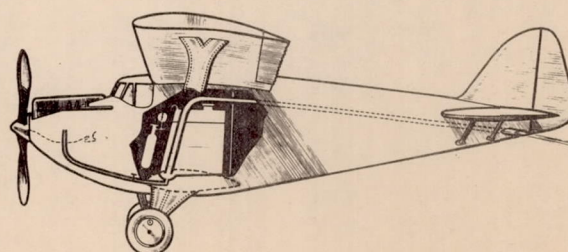


Fig.6 Quick - emptying device
expelling the fuel at
the rear of the airplane.

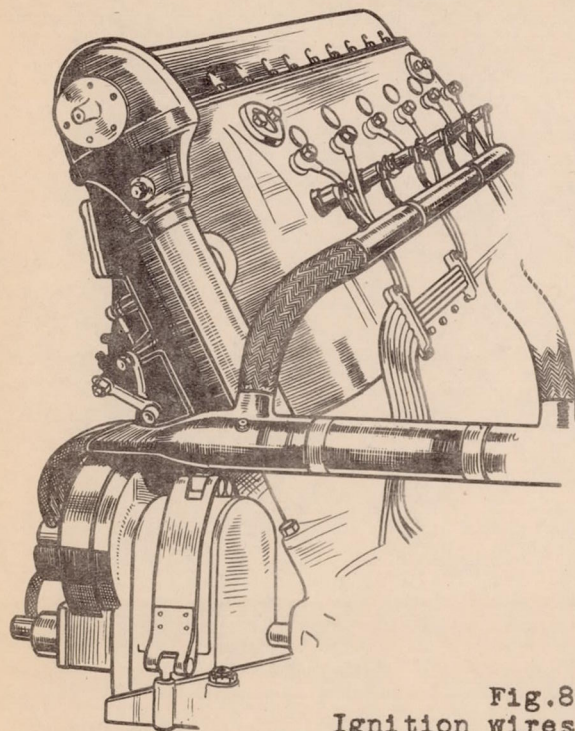


Fig. 8
Ignition wires

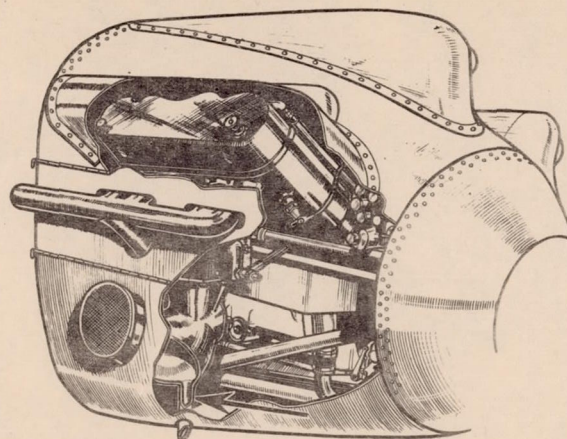


Fig. 9 Air intake with
fuel drain

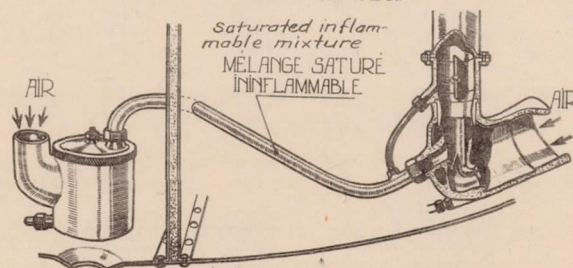


Fig. 10 Carburetor with frac-
tional carburetion.

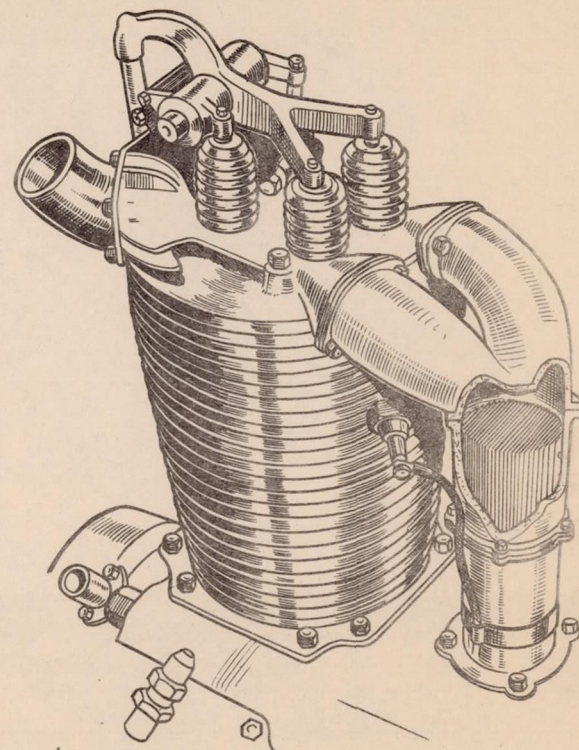


Fig. 11
Anti -
back -
fire
device.

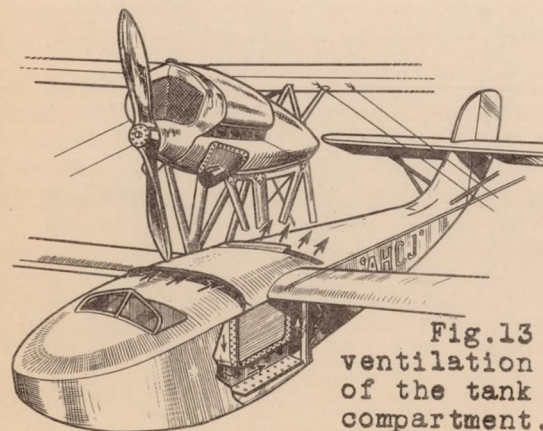


Fig. 13
ventilation
of the tank
compartment.

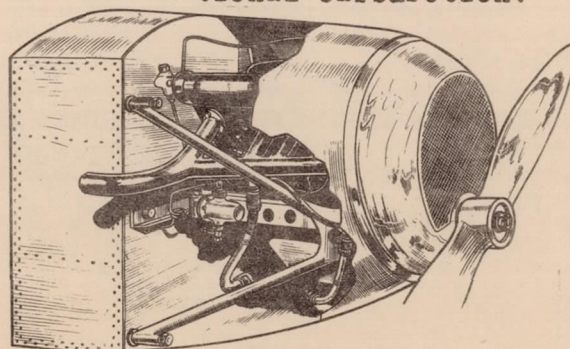
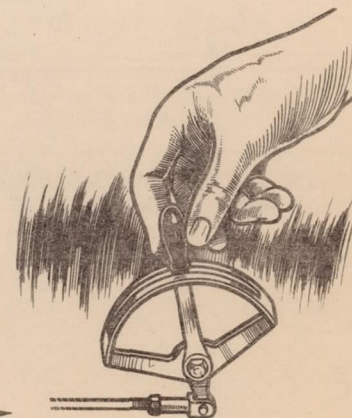


Fig. 12 Fire-
proof
bulkhead.

Fig. 14 Open
the
gas throttle
slowly.



Figs. 8 to 14